Effect of Angular-Energy Selection due to Anisotropy of Fission Neutron Emission in Non-homogeneous Environment

Nikolay V. Kornilov*

Ohio University, Department of Physics and Astronomy, Clippenger Labs, Athens, Ohio, 45701

*kornilov@phy.ohiou.edu

Abstract

There is an old problem – the contradiction between microscopic and macroscopic experimental data for Prompt Fission Neutron Spectra for ^{235}U at thermal energy. As a rule this difference was explained due to experimental uncertainties for microscopic (differential) experiments. In this paper I discuss the possible explanation of this contradiction due to strong energy-angular dependence of fission neutrons emission relative to fission fragment direction and its possible influence on macroscopic experimental results.

Keywords

Fission; Fission Neutrons Spectra Measurements

Introduction

The energy distribution of fission neutrons for ^{235}U is an important nuclear characteristic which has a very strong influence on nuclear reactor parameters such as k_{eff} value for fast reactors. PFNS can be measured in different types of experiments.

In the first type, fission neutrons are counted by a neutron detector with well known efficiency. The spectrum is measured (as a rule) by the time of flight method with counting of fission events in separate detector. In majority of these experiments neutron detector efficiency is estimated relative to standard ^{252}Cf spectrum. The description of these experiments named as differential or microscopic can be found in Ref. 1, 2.

The second type of experiment [3] is so-named macroscopic experiments. In these experiments we create the intensive neutron field corresponding to fission of ^{235}U by thermal neutrons, and we measure average cross sections for different nuclear reactions in this field. Direct comparison of these data and average cross sections calculated with evaluated PFNS, allows us to estimate the shape of PFNS and make conclusions about its uncertainties.

The average energy of PFNS from microscopic experiments is $\langle E\rangle=1.974\pm0.002$ MeV [4] and macroscopic experiments require $\langle E\rangle\sim2.031$MeV (ENDF/B-7). This main and very old problem is not solved yet (see for example Refs. 4-7). Ratios of calculated results to experimental data both for ^{252}Cf and ^{235}U spectra are shown in Fig.1. The threshold reaction cross sections were taken from IRDF-2002 data library [8,] and experimental data from [9]. ^{252}Cf standard spectrum was taken from Ref [10] and ^{235}U PFNS at thermal energy from Ref [4].

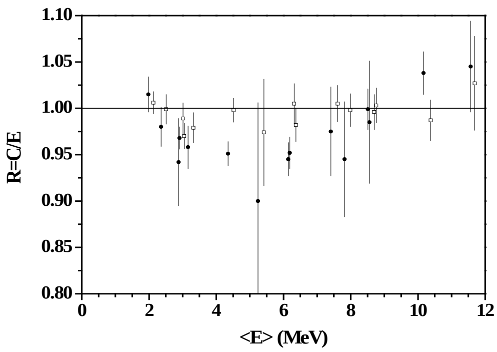

FIG.1 RATIO OF CALCULATED RESULTS TO EXPERIMENTAL AVERAGE CROSS SECTIONS FOR ^{252}CF (OPEN) AND ^{235}U (BLACK) PFNS. DATA ARE PLOTTED VERSUS AVERAGE ENERGY OF DETECTED NEUTRONS

There is very good agreement between two types of experiments for ^{252}Cf. Average ratio and standard deviation are $\langle R\rangle=0.995\pm0.015$. The PFNS for ^{235}U estimated on the basis of microscopic data cannot describe average cross sections. The difference up to 5% and clearly visible energy dependence for ratio stimulate the conclusion that neutron field created for macroscopic experiment has different shape than PFNS evaluated on the basis of microscopic data. I am discussing the possible nature of this difference in the present paper.

Peculiarities of PFN Emission

In the process of fission, the compound nucleus (traditional assumption) splits into two Fission Fragments which have double bump distribution over mass and close to Gaussian distribution of their kinetic energy. Let's assume that we have only two fragments - Light (LF) and Heavy (HF) fragments. These fragments move along the line in opposite direction with different kinetic energy per nucleon. Assume that all Prompt Fission Neutrons have an isotropic distribution in the Center of Mass System (CMS) of FF and they are emitted from fragments after full acceleration. Due to the movement of the Center of Mass, the neutrons in Laboratory System (LS) are emitted (mainly) along the direction of LF and HF.

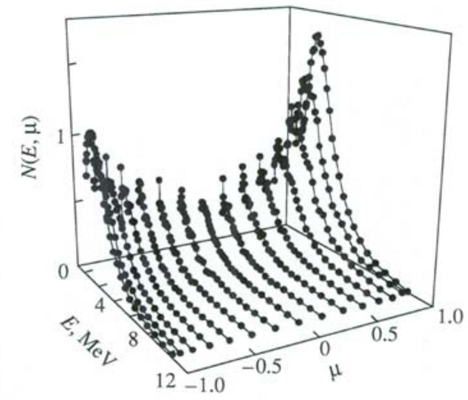

FIG. 2 EXPERIMENTAL ENERGY-ANGULAR DISTRIBUTION OF FISSION NEUTRONS IN LABORATORY SYSTEM RELATIVE TO FISSION FRAGMENT AXIS FOR THERMAL FISSION OF ^{235}U. LIGHT FRAGMENT MOVES IN M=1 DIRECTION. THE FIGURE WAS TAKEN FROM REF.11

The experimental energy-angular distribution of PFN for ^{235}U fission at thermal energy in the LS is shown in Fig.2. Calculated spectra at 90-deg, 0-deg and 180-deg are shown in Fig.3. The experimental angular distribution for ^{252}Cf spontaneous fission for both LF and HF after integration in the energy range 1-5 MeV is shown in Fig.4.

These data illustrate the well known experimental fact: average neutron energy and neutron yield are much higher along FF direction (abs(μ)~1) than in an orthogonal direction μ~0.

As a rule, there is not strong angular dependence of the fission fragment emission. Therefore, the traditional assumption is that fission fragment emission is isotropic. The consequence of this assumption is that PFN have an isotropic angular distribution also. The energy spectrum of PFN is integrated distribution of neutrons emitted relative to

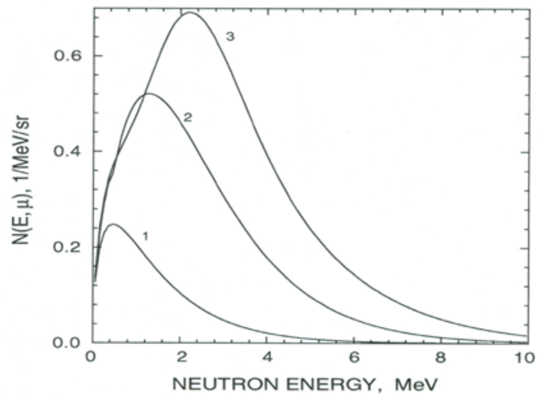

FIG. 3 PFNS FOR ^{235}U IN LS EMITTED AT DIFFERENT ANGLES RELATIVE TO FISSION FRAGMENT AXIS. 1 - SPECTRUM AT COSINE OF NEUTRON EMISSION μ=0, 2 - μ= -1 (MAINLY FROM HF), AND 3- μ=1 (MAINLY FROM LF). THE FIGURE WAS TAKEN FROM REF. 2

fixed FF direction. These data are tabulated in data libraries and are used for practical applications.

The same assumption is used for preparation of the neutron source for experiments in ^{235}U neutron field, and for treatment of experimental results. The diagram of well known MARK source is shown in Fig.5. The motivation for this construction is very simple. The thermal neutrons induce fission in which angular integrated PFN spectrum is emitted. These neutrons interact with materials of the source and create the "experimental" neutron field. The correction for interaction with environment is rather small and may be calculated on the basis of angular integrated PFNS.

In reality, after fission we have the pair of FF which emit neutrons with particular energy-angular distribution, and effect of interaction with environment depends on direction of the FF and peculiarity of environment in this direction.

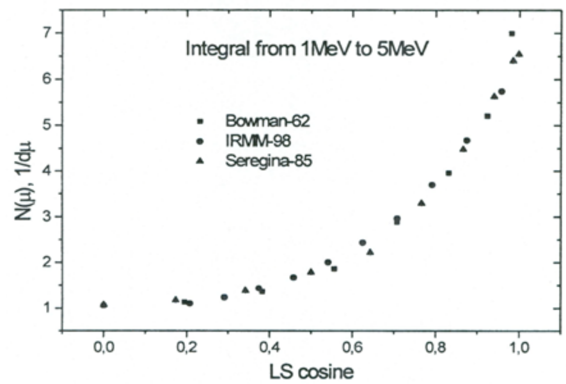

FIG. 4 ANGULAR DISTRIBUTION OF PFN FOR ^{252}CF FOR BOTH FRAGMENTS. EXPERIMENTAL DATA WERE INTEGRATED IN ENERGY RANGE 1-5 MEV. THE FIGURE WAS TAKEN FROM REF. 12

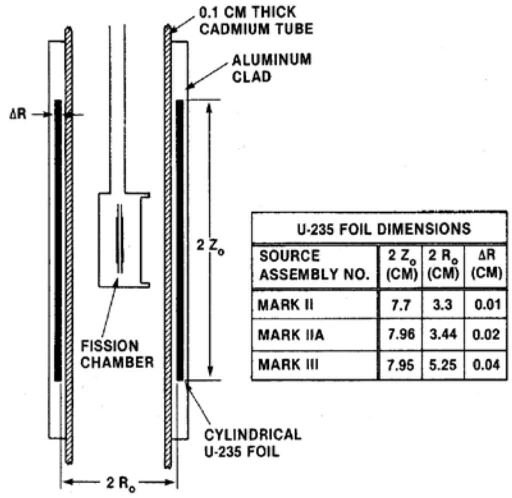

FIG.5 EXPERIMENTAL SET UP FOR MEASUREMENT OF AVERAGE CROSS SECTION IN ^{235}U FISSION NEUTRON FIELD. AL-CLAD HAS 0.7MM (IN) AND 0.75MM (OUT) THICKNESS. THE FIGURE WAS TAKEN FROM REF. 3

Effects which can Increase Average Energy on the Sample

Let's consider two fission events shown in Fig.6. Low energetic neutrons with small intensity are moving in direction of the sample in 1st event. Main component of PFN from this event with much higher energy and intensity (~7 times higher) is moving along wall of the source, and after scattering will reach activated sample.

In 2nd fission event, the sample is exposed by high energetic neutrons and contribution of scattering neutrons is rather small due to small intensity of the PFN emitted in orthogonal direction.

So, one may conclude that component of the neutron field produced due to multiple scattering in the sample environment will have higher average neutron energy in comparison with isotropic emission of average neutron spectrum.

Effect which can Reduce Average Energy on the Sample

If "weighting functions" for scattering or return of neutrons moving in to different directions inside the sample are the same for any direction of FF the final result will be the same as for emission of "average" spectrum. This case is realized in experiments with ^{252}Cf source.

Let's estimate the "weighting functions" for spectra shown in Fig. 3, having in mind that the average energy for 0- and 180 degrees is higher but for 90-degree the neutron intensity is less than for angular

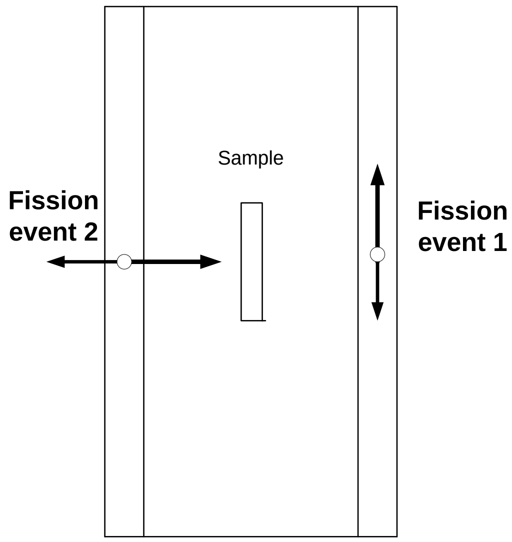

FIG. 6 EXPLANATION OF DISTORTION EFFECT FOR MARK EXPERIMENT

integrated PFNS.

In case of neutron emission along the "wall", the total cross section will be less for event 1, than for event 2. So the probability of interaction with "wall" will be less for event 1 and higher for event 2 in compare with integrated PFNS. In addition, elastic scattering has higher asymmetry for higher energy of neutrons (0, 180-deg emission). These facts reduce amount of high energetic neutrons returned back to the sample for event 1.

At the same time, inelastic scattering (first level on Al has energy 0.843 MeV) is bigger for event 1. As a consequence, the contribution of low energetic neutrons after the scattering is higher for event 1 than for event 2.

Conclusion

Multiple scattering of neutrons inside the sample environment in macroscopic experiment can provide "effect of angular-energy selection due to anisotropy of fission neutron emission in non-homogeneous environment".

It is very difficult to predict the sign of this effect. It is clear only that combination of real experimental set up and strong energy-angular distribution of neutron relative to fission fragment direction may be responsible for the difference between microscopic and macroscopic experiments.

Very important conclusions about scale (sign) of the discussed effect and its responsibility for old conflict can be made only after detail simulation by Monte

Carlo method. I hope that this publication will stimulate these investigations.

ACKNOWLEDGMENT

I am grateful to Dr. S.M. Grimes for interest to this work and useful remarks.

REFERENCES

[1] N.V.Kornilov, F.-J. Hambsch, I.Fabry et al, NSE 165, 117-127, (2010).

[2] V.M. Maslov, Yu.V. Porodzinskij, M. Baba et al, Eur. Phys.J A18, 2003, p. 93.

[3] D.M.Gilliam, et al, Reactor Dosimetry, 1985, Eds., J.P. Genthon and H. Ruttger, p. 867.

[4] N.V.Kornilov, NSE 169, 290-295 (2011) .

[5] N.V.Kornilov, A.B. Kagalenko, K.I Zolotarev, Proc. of ISINN-6, (1998), p. 242.

[6] D.G.Madland, NEA/WPEC-9, ISBN-92-64-02134-5, Nuclear Energy Agency (2003).

[7] N.V. Kornilov; Journal of The Korean Physical Society, Vol 59, 2, August 2011, pp. 1717-1720.

[8] IRDF-2002, international reactor dosimetry files, www-nds.org/irdf2002 .

[9] K.I. Zolatorev, INDC(NDC)-448, p. 25 (2003).

[10] W. MANNHART, *Proc. Advisory Group Mtg. Properties of Neutron Sources*, Leningrad, USSR, June 9–13, 1986, IAEATECDOC-410, K. OKAMOTO, Ed., International Atomic Energy Agency (1987).

[11] N.V. Kornilov, et al, Physics of Atomic Nuclei, V64 (8), 2001, p. 1372.

[12] N.V. Kornilov, et al, Nuclear Physics A 686, 2001, p. 187.